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THE IMPORTANCE OF GEODETIC CONTROL AND THE ADVANTAGES OF ITS NEW TECHNIQUES

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THE IMPORTANCE OF GEODETIC CONTROL AND THE ADVANTAGES OF ITS NEW TECHNIQUES

by

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A.1

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1. The existing vast geodetic networks of the world took many scores of years to establish. Modern techniques were not available, transportation was difficult in the early periods, instrumental equipment was bulky, and procedures were very slow, to say the least. With modern air transportation, lightweight equipment, and new techniques, geodetic triangulation or traverse of almost any desired accuracy now can be accomplished in a relatively short time.

Purposes of Geodetic Control

2. The primary function of geodetic control is, of course, to furnish the basis for mapping. A small island or an area of several thousand square miles could be mapped without geodetic considerations, but areas of continental extent should be mapped on a geodetic base. Since practically all countries are parts of continents, it follows that, if the mapping is to be at all integrated, the first consideration is that of geodetic control. Unlike mapping, which must be revised every generation or oftener because of cultural changes and need for larger scales, accurately executed geodetic control can serve its purpose a century or more after its original establishment.

3. But mapping is not the sole function of geodesy. The construction of cities and towns, of roads and highways, of railroads and airports, and the development of water resources, including the erection of huge dams for irrigation and hydro-electric power, all require large-scale surveys. It is certainly good planning to place all these engineering activities on a firm, common geodetic base.

4. There are many other uses to which a good geodetic base can be put. The delineation of national and provincial boundaries, and the survey of public and private property lines, are good examples. Surveys for pipe and transmission lines, when coordinated by geodetic control, can be accomplished in a more orderly and accurate fashion then otherwise. The exacting demands of bridge and tunnel construction can be met only by geodetic survey procedures. And when such surveys of a local nature are incorporated into the national geodetic network, they will be coordinated with the more extensive geodetic surveys essential to the construction of transcontinental railroads and highways.

Horizontal Datums

5. We have not passed from the spheroidal era to the geoidal era.[1] In fact, this transition occurred many years ago. Whereas the spheroid is a smooth mathematical surface (ellipsoid of revolution), the geoid is the actual surface of the earth as defined by the level of the sea and its extension under the continents, were it allowed to flow freely with the continents in place. Although it closely approximates a spheroid, the geoid has its humps and hollows, a description more picturesque than accurate. But this wrinkled surface, while it deviates by no more than a few tens of meters from the spheroid, causes trouble in establishing a geodetic datum.

6. It is possible through refined observations on the stars to determine astronomic latitudes and longitudes within possibly five meters on the earth's surface.

Unfortunately, such observations are necessarily referred to the direction of gravity which, in turn, is always perpendicular to the geoid, not the spheroid on which triangulation is computed. Thus, the vertical is said to be deflected and a deflection of one minute of arc, which is possible, could result in error in the position of an observation station by as much as one and one-half kilometers.

7. To establish a geodetic datum more or less free from the effects of the gravity vertical, the following procedure, in substance, has been followed by many countries. The latitude and longitude of some initial point are assumed (usually determined by astronomical methods) and the triangulation is observed radiating from this initial point. As the survey progresses, the latitudes and longitudes are calculated on the surface of the adopted spheroid. At the same time, the astronomic positions of many of these triangulation stations are determined. The differences in the latitudes, and the differences in longitudes, astronomic minus geodetic (A-G), are computed for each such station. A study of these differences, particularly in regard to their distribution, will indicate the correction which must be applied to the assumed position of the initial point to reduce the algebraic sum of the quantities (A-G) to a minimum. If there are enough of these combined geodetic and astronomic positions distributed throughout the network, this method of minimizing the (A-G) quantities should produce a satisfactory datum.

8. In the case of a small developing nation, four or five sites may be selected for astronomic observations. These should be spaced from one hundred to three hundred miles apart to form a more or less symmetrical figure. All possible lines connecting these points should then be measured by the airborne Shoran technique described later. Data are then available for an adjustment process by which the algebraic sum of the (A-G) values is minimized. The resulting datum is, in effect, an average of the individual astronomic datums and, as such, is much better than any one of them.

Horizontal Control Operations

9. Triangulation has been the basis for primary horizontal geodetic control for nearly three centuries. A triangulation system consists of a network of triangles whose vertices are marked points on the ground. All angles are accurately measured, and the lengths of the sides are computed successively through the chains of triangles, starting with a side which is actually measured on the ground. These measured sides or base lines are inserted at intervals to maintain accurate scale. Also, the bearing, or azimuth, of an occasional triangle side is observed astronomically to maintain accurate orientation.

10. The lengths of the lines vary considerably depending on the terrain and on the desired density of control points. During the early work in the United States triangle sides were seldom less than five miles in flat terrain and ranged up to 150 miles in mountainous country. Chains of quadrilaterals, called arcs, were spaced from 100 miles to 400 miles and were adjusted simultaneously to form the basis of the 1927 North American Datum. Later on, more closely spaced arcs of triangulation were added to break down this skeleton framework, and at the present time the spaces between arcs are being filled in solidly to form the area type of triangulation. For areas of limited extent, the area type of coverage should be given preference over the arc type.

11. While accuracy in angle measurement has not increased much in the past century and a half, there has been a tremendous improvement in instrumental equipment. The best theodolites in the early days of geodetic operations had circles as large as 36 inches in diameter, whereas the circles of modern first-order theodolites are less than 6 inches. Also, the modern instruments are much more precise. Astronomic equipment also has been reduced in size and increased in efficiency. But the most spectacular innovation deals with the measurement of distances.

Electronic Surveying

12. As a result of blind bombing techniques and rapid advance in electronics during World War II, the geodesist found that he had a new yardstick to work with--the speed of

electro-magnetic waves. He had the means, through electronic distance measurement, to increase the accuracy of his work, reduce the costs, and even accomplish surveys theretofore impossible.[2]

13. Airborne Shoran[3], was the first of these methods to be employed in geodesy. The procedure involves using Shoran equipment in an airplane to continually record the distances to each of two ground stations as the airplane flies a course perpendicular to a line connecting the stations. The distance between the stations is then determined from the minimum air-distant sum recorded, and the length is reduced to sea level. Shoran employs radio waves in the high frequency band, and length determinations have an accuracy of the order of a few meters. There are problems in correcting such observations for the speed of radio waves in actual atmospheric conditions, but the method makes possible surveys over wide stretches of water or in regions highly inaccessible and not adapted to the classical methods. Major Shoran projects, later called Hiran because of higher instrumental accuracy, have provided networks over the Caribbean area; northern Canada; the North Atlantic, connecting the European and American continents; and over certain Pacific island areas. This Hiran approach, though costly, is one way to rapidly arrive at a geodetic datum for areas far removed from well established datums.

Satellite Triangulation

14. With the advent of the artificial earth satellite, an entirely new approach to geodetic problems became available.[4] A continuing problem of interest on a world basis to geodesists is the interconnection of the continental and island geodetic datums and ultimately the establishment of a valid world geodetic datum. While progress has been made in intercontinental geodetic ties, the launching of artificial satellites offered the first truly universal technique of accomplishing these ties on a world wide basis. The necessary triangulation to provide these ties can now be accomplished by means of simultaneous observations on artificial earth satellites, the passive type, as ECHO I, and the rebound type, A-13, to be launched in 1963. These satellites are large, in high orbits, well illuminated by the sun and have long lives, allowing time for observations on a protracted time scale so necessary for optical photography, since about 70 per cent of the earth is blanketed by clouds at any given epoch of time. The technique will also have direct application in the dynamic studies of the earth's asymmetric gravity field, and in improving our knowledge of the earth's size and shape.

15. The U. S. Coast and Geodetic Survey has initiated a program of satellite triangulation. From a single camera site a satellite is photographed against the stars at a known time, and the position of the satellite image relative to the star images on the photographic plate is measured. The right ascension and declination of each star, obtained from star tables in the vicinity of the satellite image (about 20 stars), together with the plate measurements, are used in an adjustment procedure, or plate reduction, to obtain a right ascension and declination of the satellite. That is, a direction is obtained in space from the station, not involving the gravity vector at the camera site. Each camera plate has a succession of time-correlated images on it, and thus a plate reduction for each image gives a series of time-correlated right ascensions and declinations. These may be converted into corresponding time-correlated azimuths and elevations at that camera station. If a camera is used simultaneously from each of the ends of a known earth base line, then for each simultaneous satellite image on their plates there is a triangle formed by the satellite image and the two stations. The time-correlated azimuths and elevations from each camera plate are used along with the known length of the base line to compute the sides and angles of each space triangle. If a third camera of unknown ground position also photographs the satellite at the same time, then its time-correlated azimuths and elevations (matched in time with those of the other two) allow determination of its position with respect to the other two. The additional angular data will allow computation from the given base line through several sets of space triangles (successive tetrahedrons) to the third camera site. From this beginning the process can be continued and oceans

can be bridged, the satellite being used as a high flare in the sky to connect geodetic datums.[6]

16. To scale the satellite triangulation, base lines hundreds of miles long will be established accurate to 1 part per million. These base lines, in the form of highly precise traverses, will cross the entire continental United States in both directions. The instrument to be used is the Geodimeter, the characteristics of which are covered later. A simultaneous adjustment of this network will provide a geodetic base of five or ten times the present accuracy. Present plans call for establishing this very accurate geodetic network and then extending it by satellite triangulation to Puerto Rico, the Bahama Islands, Bermuda, and Panama with possible connections to the northeast coast of South America and the western coast of Africa. Further expansion is contemplated to the northwest to include Alaska and the Aleutian Islands. Extension can then be made to the Pacific Islands, such as Hawaii, the Tokyo Datum, Southeastern Asia, Southwest Pacific and Australia. With international cooperation an accelerated schedule could be devised, and the means provided for extending the net over South America, Europe, Asia, and Africa.

17. The camera system adopted by the Coast and Geodetic Survey for satellite triangulation is an adaptation of the Wild BC-4 with an especially designed lens system for photographing satellites, and with associated electronic timing and synchronization systems. A specially designed "chopping" shutter allows interruption of the satellite trail for timing purposes. Present plans include use of atomic clocks at station sites to eliminate timing errors in the coordination of the observations from the several station sites.

18. Five systems of four cameras each for operation in the several continental and island areas of the world would be adequate to assure success in the program. If, in addition, the many observatories throughout the world could participate, the objective of a rigid accurate worldwide reference network of geodetic stations for the precise observation of satellite orbits, study of the earth's figure, etc., would probably be realized much sooner.

19. The high accuracy Geodimeter traverse program is under way in the United States. The present plan is to cross the country east and west with about four, and north and south with about seven, of such traverses. A special design for the traverse surveys is being employed. At every other traverse station a second station monument is placed close to the main station (25 to 50 meters). In this way, long sliver quadrilaterals are formed. All angles and sides are measured. The short 25- to 50-meter length is taped. In this way rigid checks are obtained for both length and angle observations as the traverse survey progresses. Laplace azimuths are observed at every other traverse site, usually at the single monumented station. Since the Geodimeter-measured legs of the traverse are roughly eight to ten miles long, there will be a Laplace azimuth and a deflection of the vertical determined every 15 or 20 miles along the traverse. Thus, as a by-product, valuable information will be available for the study of the spheroid-geoid relationship.

Modern Equipment

20. The Geodimeter is perhaps the most revolutionary geodetic instrument in the long history of geodesy. It operates on a modulated light source, and since the speed of light has now been determined with an accuracy of better than one part per million, the Geodimeter can be and has been used to measure the lengths of lines to an accuracy of one part per million. It tremendously reduces the time and costs of measuring a base line. This means that the less developed countries have a tool of high geodetic precision in getting surveys under way at the outset. The tedious clearing, staking, and taping of a base line are completely obviated. The United States plans to use the Geodimeter to upgrade the scale of its geodetic networks, in addition to using it for the proposed satellite triangulation.

21. Unlike the Geodimeter, the Tellurometer operates on radio microwaves in the 10-cm. range. A similar and more recently developed device, the Electrotape, operating in the 3-cm. range, gives promise of high accuracy over a wide distance range. This

type of electronic distance-measuring equipment has proven to be another valuable tool for geodesy. It is not a competitor of the Geodimeter but is complimentary to it. The Tellurometer has two distinct advantages over the Geodimeter. It can be used in the daytime and even in foggy or hazy weather, and it is much lighter in weight. The system consists of two instruments: the Master and the Remote which, in recent years, have been made interchangeable. Whereas the Geodimeter has a basic uncertainty of one or two cms., the Tellurometer has such an uncertainty of about six or eight cms. Moreover, the radio wave type of instrument can have large errors due to reflected waves which are not present in the light wave type of equipment.

22. But the Tellurometer and Electrotape, when properly used, can yield second-order accuracy provided the lines to be measured are at least two or three miles; and they have been used to scale first-order triangulation where the lines were ten or more miles in length. When used in this fashion at least two lines of a triangle are measured to guard against too large an error.

23. The Tellurometer has been employed in the United States in supplying control for the interstate highway system. It is used both for measuring the legs of traverse surveys and in combined traverse and triangulation surveys. In adjusting the work to high-order triangulation, the average correction to a Tellurometer observation has been about 1:35,000. Tellurometer or Electrotape traverse would be an excellent method for filling in the gaps between first-order geodetic control with second-order traverses in new areas.

24. These items of new equipment, by which lengths of survey lines can be quickly and accurately measured, provide a great flexibility for the emerging nations in planning the extension of geodetic control. Triangulation, electronic distance-measured traverse, trilateration, or various combinations of these can be adapted to best suit climate, terrain, and any other conditions that may prevail.

Vertical Datums and Control

25. The establishment of a vertical control datum is completely separate from that of a horizontal datum.[7] Most of the developed nations of the world depend on the mean level of the sea for elevation datum.

26. Ideally, mean sea level is defined as the equipotential surface which the oceans of the earth would assume if not disturbed by the tides and meteorological effects. The geodesist in starting his precise leveling from a point on such an ideal surface would have no difficulty in closing his circuits on other such points along the coast. Elevations so derived would refer to a universal and unique mean sea level, an equipotential surface with zero potential. But, as usual, the ideal situation does not exist. The effects of the winds, ocean currents, atmospheric pressures, configuration of the coastline, and other disturbing elements, preclude an exact determination of this ideal surface by averaging the varying height of the sea. And this is so, even though tidal observations are taken over the full tidal cycle of 19 years. It becomes necessary, therefore, to establish tide gages and make observations at a number of stations along the coast.

27. The selection of locations for tide gages for the control of a level net depends on many factors, such as the coast line of the country under consideration, free communication for the tide, sufficient depth of water at all stages of the tide, freedom from runoff effects, and access to the interior to establish ties to the control nets. What is desired is a location at which zero potential can be determined. Mean sea level, as determined by averaging the hourly heights of the tide over a long period of time, can approximate this zero potential but cannot exactly be equal to it, since it is extremely difficult to remove all of the disturbing elements.

28. The density of tide station distribution is one which should not arbitrarily be placed on a distance basis. If along a coast the tidal regime is about the same for a long distance, control tide stations spaced 100 miles apart can be considered as adequate and desirable distribution. However, there are a number of places where the type of tide varies considerably at two localities much less than 100 miles apart. In these cases, a study should be made of the area and a sufficient number of control tide stations

established so that all of the various tidal conditions will be adequately covered.

29. In using mean sea level as zero in the establishment of a vertical control datum it is important that the observations be simultaneous. Along the coasts of the United States mean sea level is rising in varying amounts up to 0.021 foot per year. Along the Atlantic coast the rate is about 0.011 foot per year, while along the Gulf coast it is about 0.021 foot per year and on the Pacific coast about 0.005 foot per year. In view of the changes in mean sea level, it is readily seen that if data for different epochs were used there would be differing results.

30. The International Union of Geodesy and Geophysics has recommended that each country consider the computation of geopotential heights for each bench mark as well as orthometric heights. The geopotential heights would be based on measured values of gravity determined along the route of the leveling. This might make it desirable to use a single zero potential determination as a basis, especially if the level net is of high quality. Some countries have used mean sea level as determined at only one location as a basis for their elevations, as in the case of Great Britain.

31. The classical method of running levels to determine elevations has undergone little change. In order to secure high accuracy, the lines of sight seldom exceed 100 meters and on steep grades these are considerably less. In regions where there are no railroads or very few roads of any kind, the progress is apt to be slow due to transportation difficulties. The method, however, does yield high accuracy in comparison with determining elevations by observing vertical angles over a triangulation net. The classical method must be used as the basis of vertical control in any region where accuracy greater than that required for topographic mapping is desired. A new area should be covered with a network of leveling lines of first-order accuracy spaced from 50 to 100 miles in both directions. First-order leveling is double run, once in each direction. Second-order leveling, which may be used to break down the first-order loops, is generally run in one direction only.

Plane Coordinates and Projections

32. Over areas of large extent, precise control surveys must be computed and adjusted on the curved surface of the earth, else unmanageable confusion will result. The coordinates resulting from such computations are necessarily expressed in terms of latitude and longitude. After this has been accomplished, thought must be given to means of both mapping and surveying on a plane surface. For most types of engineering and cadastral surveys, it is almost mandatory that a system of plane coordinates, based uniquely on the adopted geodetic datum, be made available.

33. Projections may be said generally to serve two primary purposes--cartographic and geodetic or, in other terms, mapping and surveying. In some nations more than one type of projection, each of varying extent, is employed, such as in the United States. For cartographic purposes, the United States uses the Lambert conformal conic projection of zones some 25° in width for its sectional aeronautical charts and the same projection for zones 4° wide for the world aeronautical chart series. The Mercator projection is the basis for nautical charting in the United States. The universal transverse Mercator projection with zones extending indefinitely north and south and 6° east and west, is the basis for both geodetic and cartographic work of the Department of the Defense. For geodetic purposes only, the Lambert and transverse Mercator projections are used as the basis for state plane coordinates in the 50 states.[8] There is one exception to this, the oblique Mercator projection for Southeast Alaska.

34. In order that the survey angles, as measured on the ground, be preserved on the projection, at least with certain limitations, the projection must be of the conformal type. The kinds of projections used by the nations of the world are the Lambert conformal conic, the Mercator in its various forms, and the stereographic projections, all of which are conformal.

35. In choosing a particular projection for a given area certain factors must be considered. If the extent is greater in the north-south direction than in the east-west direction, the transverse Mercator projection is indicated. On the other hand, the Lambert conformal is best for great East-West extent. For areas more or less symmetrical in shape in all directions, the stereographic projection will be the most suitable.

FOOTNOTES

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